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09/509428

430 Rec'd PCT/PTO 28 MAR 2000

AN ELECTRIC POWER PLANT

Technical Field

The present invention relates to an electric power plant comprising at least one rotating main electric machine, intended to be connected directly to a distribution and transmission network and comprising at least one electric winding. The invention relates also to the use of a rotating electric machine in an electric power plant.

Background

The rotating electric machine, which is included in the power plant, may for example be a synchronous machine, a double-fed machine, an external pole machine or a synchronous flux machine.

A transformer has been used up to the present to step-up the voltage to the level of the network i.e., in the range of 130 - 400 kV in order to connect machines of the type mentioned above to distribution or transmission networks, commonly referred to below as power networks.

A generator with a rated voltage of up to 36 kV is described by Paul Siedler in an article entitled "36 kV Generators Arise from Insulation Research", in Electrical World, 15 October 1932, pp. 524-527. These generators comprise windings of high voltage cable, in which the insulation is divided into different layers having different dielectric constants. The insulation material being utilized consists of different combinations of the following three components: mica foil-mica, lacquer and paper.

It has proved that, by manufacturing the above-mentioned winding for the machine of an insulated electric high voltage conductor having a solid insulation of a similar type as for cables for the transmission of power, the voltage of the machine may be increased to such levels that the machine may be connected directly to any power network without an intermediate transformer. The transformer may thus be dispensed with. A typical power range for these machines is 30 - 800 kV.

The aim of the present invention is to provide an electric power plant having at least one main electric machine which is directly connected to transmission

and distribution networks and which is magnetizable from an excitation system which lacks slip rings and is simple to maintain.

Summary of the invention

This aim is achieved by an electric power plant of the kind described in the introductory part of the description, with the characteristic features described in Claim 1.

The insulated conductor or high voltage cable used in the present invention is flexible and bendable and of the type described in more detail in WO 97/45919 and WO 97/45847. Additional descriptions of the insulated conductor or cable can be found in WO 97/45918, WO 97/45930 and WO 97/45931.

Thus, in a device according to the invention the windings are preferably composed of cables having solid, extruded insulation, of a type currently used for power distribution, such as XLPE cables or cables having EPR insulation. Such a cable comprises an inner conductor composed of one or more strands, an inner semiconducting layer surrounding the conductor, a solid insulating layer surrounding the inner semiconducting layer and an outer semiconducting layer surrounding the insulating layer. Such cables are bendable, which is an important property in this respect since the technology for the machines of the invention, is based primarily on a winding system in which the winding is formed from cables which are bent during assembly. The bending ability of an XLPE cable normally corresponds to a radius of curvature of approximately 20 cm for a cable with a diameter of 30 mm, and a radius of curvature of approximately 65 cm for a cable with a diameter of 80 mm. In the present application the designation bendable is used to indicate that the winding is bendable down to a radius of curvature in the order of four times the cable diameter, preferably eight to twelve times the cable diameter.

The winding should be constructed so as to retain its properties even when it is bent and when it is subjected to thermal or mechanical stress during operation. It is vital that the layers retain their adhesion to each other in this respect. The material properties of the layers are decisive here, particularly their elasticity and relative coefficients of thermal expansion. In an XLPE cable, for example, the insulating layer consists of cross-linked, low-density polyethylene, and

the semiconducting layers consist of polyethylene with both soot and metal particles mixed therein. Changes in the volume as a result of temperature fluctuations are completely absorbed as changes in the radius of the cable and, thanks to the comparatively slight difference between the coefficients of thermal expansion of the layers in relation to the elasticity of these materials, the radial expansion of the cable may take place without the loss of adhesion between the layers.

The material combinations stated above should be considered by way of example only. Other combinations fulfilling the specified conditions as well as the condition of being semiconducting, i.e. having a resistivity within the range of 10^{-1} - 10^{6} ohm-cm. e.g. 1 -500 ohm-cm or 10 - 200 ohm-cm naturally also fall within the scope of the invention.

The insulating layer may consist, for example, of a solid thermoplastic material such as low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), polybutylene (PB), polymethyl pentene (PMP), cross-linked materials such as cross-linked polyethylene (XLPE), or rubber such as ethylene propylene rubber (EPR) or silicone rubber.

The inner and outer semiconducting layers may be of the same basic material but with particles of conducting material such as soot or metal powder mixed therein.

The mechanical properties of these materials, particularly their coefficients of thermal expansion, are affected relatively little by whether soot or metal powder is mixed therein or not, i.e. in the proportions required to achieve the conductivity necessary according to the invention. Thus, the insulating layer and the semiconducting layers have substantially the same coefficients of thermal expansion.

Ethylene-vinyl-acetate copolymers/nitrile rubber, butyl graft polyethylene, ethylene-acrylate copolymers and ethylene-ethyl-acrylate copolymers may also constitute suitable polymers for the semiconducting layers.

Even when different types of material are used as a base in the various layers, it is desirable for their coefficient of thermal expansion to be substantially the same. This is the case in the combination of the materials listed above.

The materials listed above have a relatively good elasticity, with an E-modulus of E < 500 MPa, preferably < 200 MPa . The elasticity is sufficient for any

minor differences between the coefficients of thermal expansion for the materials in the layers to be absorbed in the radial direction by the elasticity so that no cracks or other damage arise and so that the layers are not released from each other. The material in the layers is elastic, and the adhesion between the layers is at least of the same magnitude as the weakest of the materials.

The conductivity of the two semiconducting layers is sufficient to substantially equalise the potential along the respective layers. The conductivity of the outer semiconducting layer is sufficiently large to contain the electric field in the cable, but at the same time sufficiently small to not give rise to significant losses due to currents induced in the longitudinal direction of the layer.

Thus, each of the two semiconducting layers essentially constitutes one equipotential surface, and these layers will substantially enclose the electric field between them.

This does not, of course, exclude one or several semiconducting layers from being arranged additionally in the insulating layer.

According to advantageous embodiments of the power plant according to the invention, the brushless excitation system comprises a rotating part with an exciter connected to rotating controllable semiconductor elements with associated control equipment for rectifying the supply voltage obtained for supplying the field winding of the machine, and furthermore a communication unit is adapted for wireless communication between stationary regulator equipment and the control equipment which is included in the rotating part. By exploiting the controllable semiconductor elements in this way, improved regulating properties are achieved in that positive as well as negative excitation voltages can be achieved simultaneous with the simple maintenance characterizing brushless excitation systems. Faster response and transient times are obtained during network interference in that the excitation system can generate positive as well as negative excitation voltage.

According to other advantageous embodiments of the power plant according to the invention, the exciter is designed with double stator windings for the excitation of the main electric machine as well as the auxiliary power machine. The stator windings are hereby advantageously connected to each of their re-

spective controllable semiconductor elements with respective control equipment for individual control of the supply of the auxiliary power machine and the main electric machine. The control equipments are advantageously adapted to generate control pulses to the controllable semiconductor elements in a manner self-compensating for variations in the supply voltage to the semiconductor elements. Flux changes necessary for voltage variations suited to the excitation requirements of the machine will thereby not influence the excitation of a voltage regulated machine generating auxiliary power. A constant voltage at the auxiliary power busbar and a voltage rise for the generation of extra, temporary short-circuit power during faults are enabled by voltage regulation of the machine generating auxiliary power.

Brief description of the drawings

To explain the invention in greater detail, embodiments of the electric power plant according to the invention will now be described in more detail with reference to the accompanying drawings, wherein

Figures 1 to 3 show diagrams of three different embodiments of the power plant according to the invention,

Figure 4 shows a more detailed embodiment of the rotating part in the excitation system in connection with the embodiments according to Figures 1-3,

Figure 5 illustrates a principle for reduction of exciter losses by supply voltage, which is adapted to the requirements, to the controllable, rectified semiconductor elements in the form of a rotating thyristor bridge,

Figure 6 illustrates a principle for self-compensating control pulse generation for control of the rectifying semiconductor elements, and

Figure 7 shows a cross-section view of the insulated conductor which is used in machines in the power plant according to the invention.

Description of the preferred embodiments

Figure 1 shows a first embodiment of the electric power plant according to the invention, comprising an electric machine G1 and an auxiliary power machine in the form of a permanent-magnet generator G2. The machine G1 is excited by means of an excitation system comprising a rotating part 1 with an exciter G3, controllable rectifying semiconductor elements in the form of a thyristor bridge 21 with a control-pulse generator 22, a bidirectional overvoltage protection device 24, and a rotating field winding 30 of the electric machine G1. Further, the rotating part 1 comprises control equipment 23 for control of the thyristor bridge 21 via the control pulse generator 22. The control equipment 23 is also connected to current-measuring members 25, 27 arranged on each side of the thyristor bridge 21. A filter transformer 28 is connected between the output side of the exciter G3 and the control pulse generator 22 and the control equipment 23 for determining and rotating the phase position for firing the thyristors for the purpose of voltage adaptation. Variations of the input voltage may thus be compensated for by control of the thyristor firing.

The rotating part 1 of the excitation system further comprises a supply device 26 for the electronic devices of the rotating part 1.

A bidirectional overvoltage protection device 24 serves as overvoltage protection for the field winding 30 and diverts induced currents in case of a fault. The overvoltage protection device 24 comprises a current-limiting resistor 34, which makes possible continued operation when the overvoltage protection device 24 is activated. An activated protection device 24 is reset by temporary sign reversal of the field voltage.

The control equipment 23 is further connected to a rotating communication unit 29 for wireless communication with a stationary communication unit 34, which in turn is connected, via the control equipment 23, to regulator equipment 33 for control of the power stage, formed by the thyristor bridge 21 and the control pulse generator 22, from the regulator equipment 33. In this way, the excitation of the machine G1 is thus controlled from the stationary regulator equipment 33 by regulating the degree of modulation of the thyristors of the bridge 21.

Other monitoring and regulating functions may also be carried out from the stationary regulator equipment 33.

The signal transmission between the stationary and rotating communication units 34, 29 may be performed with the aid of frequency-modulated infrared light. Each unit 34, 29 is then provided with at least one transmitting and one receiving part, comprising a number of light-emitting diodes. The number of light-emitting diodes and the location on the rotating part 1 are such that no blind angles may occur between the transmitting and the receiving units.

Alternatively, the communication between the stationary and rotating communication units 34, 29 may take place capacitively or inductively, or by radio communication.

The rotating exciter G3 is of synchronous-machine type with a rotating stator winding, which is excited by a smaller static exciter, comprising converters 42 for supplying the stationary field winding 44. The static exciter is supplied from the auxiliary power generator G2 and the excitation is controlled by the regulator equipment 33 by controlling the supply voltage of the converter bridge 42. The supply voltage to the thyristor bridge 21, which in turn supplies the field winding 30 of the machine G1, may thus be regulated by changing the magnetic flux in the rotating exciter G3.

The auxiliary power generator G2 further supplies a busbar 36 for distribution of the auxiliary power via equipment 35 for voltage, and possibly frequency, adaptation.

The output voltage of the machine G1 is fed back, via a connection 46, to the regulator equipment 33 for automatic adaptation of the supply voltage of the rectifying semiconductor elements 21 to the actual operating conditions.

By such a requirement-adapted control of the supply voltage of the thyristor bridge 21, the losses in the rotating exciter G3 are reduced. In case of transients currents, the field voltage may be increased. Stationary operation stability thus entail a low peak-voltage factor and transient stability entails a high peak-voltage factor. The peak-voltage factor may be defined as the ratio of the maximum possible field voltage and the field voltage at rated load and a hot field winding. Compare with the description of Figure 5 below.

During stationary operating conditions, the voltage of the exciter G3 is thus increased or decreased in proportion to the desired value fed into the regulator equipment 33. During transient stability and voltage regulation (the regulator may alternatively be arranged as a field-current regulator), the supply voltage is increased to a maximum value until stationary operation stability has been restored. The return to the actual voltage level for stationary operation stability may then be performed either instantaneously or via a ramp function with a controlled rate of change. The control pulse generator 22, with the function of compensating the firing instants of the thyristors 21 in case of voltage variations, maintains the field current constant during the transition process.

The line voltage may be fed back to the regulator equipment 33, via a connection 48, for use when phasing the machine G1.

Figure 2 shows an alternative embodiment, in which the auxiliary power generator G2 is a synchronous machine and the rotating part 1 comprises an exciter G3 in the form of a permanent-magnet generator with double stator windings for excitation of the machine G1 and the auxiliary power generator G2 via a respective thyristor bridge included in the rotating part 1. In this embodiment, the rotating part 1 thus comprises a unit 51 of a power stage, an overvoltage protection device and control equipment for supplying the field winding 30 of the machine G1, as well as similar devices, represented by the block 52 in Figure 2, for supplying the auxiliary power generator G2.

In the same way as the control equipment 23 for the excitation of the main machine G1 is connected to stationary regulator equipment 53 via communication units 29, 34 for wireless communication, as described with reference to Figure 1, the corresponding control equipment for the excitation of the auxiliary power generator G2 is connected to the regulator equipment 53 via identical communication units 54, 57. In this embodiment, the regulator equipment 53 comprises two voltage regulators 58, 59 for maintaining constant the voltages of both the machine G1 and the auxiliary power generator G2 by excitation control.

The permanent-magnet generator G3 comprises a stationary permanent-magnet rotor 60, supplemented by a few winding turns 61, which are supplied via the converter 62 from the auxiliary power generator G2 for controlled flux

changes. In such a permanent-magnet rotor 60, there is always a field even at zero voltage.

The control pulse generation for the thyristor bridges is based on a principle for self-compensation for variations in the supply voltage of the thyristor bridges. Flux changes which are necessary for voltage variations for adaptation to the excitation requirement of the machine G1 will thus not influence the excitation of the voltage-regulated auxiliary power generator G2.

The voltage regulation of the auxiliary power generator G2 is made possible by the voltage regulator 58 included in the regulator equipment 53, which voltage regulator makes it possible either to maintain a constant voltage on the auxiliary power busbar 36, ALT. 2, or to increase the voltage for temporary generation of extra short-circuit power in case of a fault, ALT. 1. The voltage of the auxiliary power generator G2 is thus increased by increasing its excitation.

In the embodiment shown in Figure 2, the auxiliary power generator G2 is a synchronous machine, as mentioned above, of a size smaller than that of machine G1. Also the power stage 52 for supplying the field to the auxiliary power generator G2 is smaller than the corresponding power stage 51 for supplying the field of the machine G1.

The other parts of the embodiment of Figure 2 are identical with the corresponding parts of the embodiment shown in Figure 1 and will therefore not be described in more detail here.

Figure 3 shows another embodiment of the power plant according to the invention. This embodiment differs from the embodiment shown in Figure 2 in that the exciter G3 is of an asynchronous machine type with double rotor windings for excitation of the machine G1 and the auxiliary power generator G2.

The asynchronous machine G3 with reversed direction of rotation functions as a rotating transformer and also makes possible excitation during downtime.

In addition to the change of the exciter G3 described above, this embodiment corresponds to the one described in Figure 2 and will not, therefore, be described in more detail here.

Figure 4 shows in more detail an embodiment of the rotating part 1 in the embodiments according to the preceding figures. The rotating part 1 thus comprises a part 71 for excitation and protection of the machine G1. The part 71 comprises a thyristor bridge 81 with a control pulse generator 82, which has been described above, connected to the output of a selector 83, which is adapted to select the smallest of an input signal in the form of a control signal from the regulator device (not shown), received over the wireless communication units 93, 94, and a signal from a regulator unit 85. This regulator unit 85 is adapted to receive, as input signals, a set-point or limit-value signal from the communication unit 93 as well as a signal representing the field current Ifield, measured by means of the current-measuring device 95, for manual control or limitation of the field current.

Further, a current-measuring unit 86 is connected to the communication unit 93 and to the current transformers 87 for measuring the alternating currents from the rotating exciter G3, in this case of a permanent-magnet generator type, and supplying corresponding measurement signals Ir, Is It to the communication units 93.

The current on both the direct-voltage side and the alternating-voltage side is measured with the current-measuring devices 95 and 86, 87, respectively, and the difference current is used as a criterion for resetting the overvoltage protection device 84, the resetting being performed with the aid of a temporary negative excitation voltage.

A voltage-measuring unit 89 is adapted to measure the voltage on the output of the rotating exciter G3 with a filter transformer 88, as described above, and to supply corresponding signals Ur, Us, Ut to the communication unit 93. The voltage signal sensed by the transformer 88 is also supplied to the control pulse generator 82, where it is compared with the signal from the selector 83 for controlling the thyristor bridge 81 in dependence thereon.

Still another voltage-measuring unit 70 is adapted to measure the field voltage and to supply a corresponding measurement signal Ufield to the communication unit 93 for transmission to the stationary communication unit 94 and the regulator equipment.

Further, there is a bidirectional overvoltage protection device 84 for the field winding 64 of the machine G1 as previously described.

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A unit 71 for detection of ground fault in the field winding 64 as well as a transducer 72 for measuring the temperature of the field winding 64 are also provided.

Figure 4 further shows the permanent-magnet rotor 60 of the exciter G3 with a supplementary winding 61, as described with reference to Figure 2, as well as a feedback connection 46 from the machine G1 to the regulator equipment and a connection 48 for supplying a measured line voltage to the regulator equipment, as described with reference to Figure 1.

Figure 5 shows a diagram illustrating a solution in principle for reduction of exciter losses by adapting the requirement of the supply voltage to the rotating thyristor bridge. Ufl/0 designates the field voltage in an unloaded machine, Ufl/1 designates the field voltage at rated load on the machine, Ufc designates maximum field voltage during stationary operation (stationary operation stability), U_{peak} designates maximum field voltage during transient operation (transient stability), U_{ac} designates the supply voltage of the thyristor bridge, and U_{dc} designates the actual field voltage = $1.35 \times U_{ac} \times \cos a$.

In case of transient disturbances, the maximum field voltage U_{peak} thus increases, at t1, as does the peak-voltage factor, which is defined above. In this way, improved efficiency of the rotating exciter during steady-state conditions is obtained.

Figure 6 illustrates in more detail the principle of self-compensating control-pulse generation for the thyristor bridge in the power plant according to the invention.

From the filter transformer 88, the control pulse generator 82 is supplied with the phase voltages UR, US, UT (cf. Figure 4 and the upper curve of Figure 6). An internal auxiliary voltage U+R, which is shifted in phase 60 electrical degrees from the phase voltage UR, is generated. The output signal UC of the regulator 83, 85 in Figure 4 is supplied to the control pulse generator 82 and is compared in a comparator with the auxiliary voltage U+R and when the signal UC is equal to the auxiliary voltage U+R and US is greater than UR, a firing signal is

supplied to the relevant thyristor in the S-phase in the bridge 81 in Figure 4, marked in the lower part of Figure 6, whereupon the conduction interval of the thyristor follows.

The firing instant is thus controlled both by the changes in the regulator signal U_c and by changes in the signal level of the internal auxiliary voltage U+R.

To enable direct connection of the electric machine and possibly the auxiliary power machine, as previously discussed, the machine has windings, comprising an insulated conductor of the kind shown in Figure 7. Figure 7 thus shows a cross-section view of an insulated conductor 11 comprising a number of strands 35 with a circular cross section of, for example, copper (Cu). These strands 35 are arranged in the centre of the insulated conductor 11. A first semiconducting layer 13 is arranged around the strands 35. An insulating layer 37, for example an XLPE insulation, is arranged around the first semiconducting layer 13. A second semiconducting layer 15 is arranged around the insulating layer 37. The insulating conductor or cable is bendable and this property is maintained in the insulated conductor during its service life, and the three layers mentioned are designed so as to adhere to one another even when the cable is bent. The insulated conductor has a diameter in the interval 20-250 mm and a conductor area in the interval 80-3000 mm^2.

A plurality of modifications of the embodiments described above are, of course, possible. Thus, for example, the phase position for the supply voltage of the converter may be transformed to the stationary side, which makes possible a stationarily arranged control pulse generator and transmission of the starting instant of the firing pulses to the rotating part in a wireless manner, as described above. Further, for example, the supply voltage to the rotating supply part may be transformed to the rotating part by means of a ring transformer. According to additional possible alternatives, current, voltage and temperature measurement may be realized by the use of fibre-optic technology.